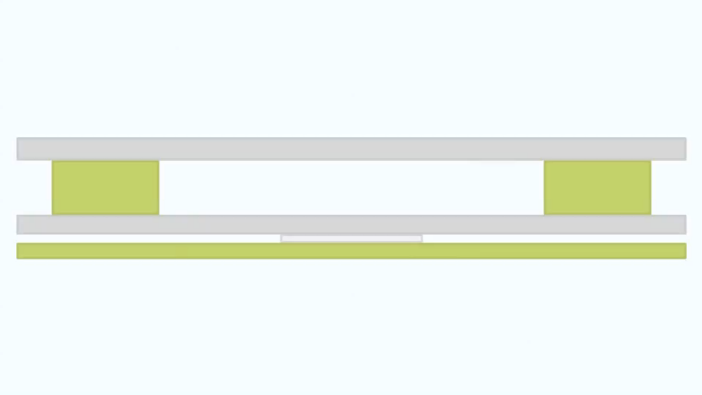
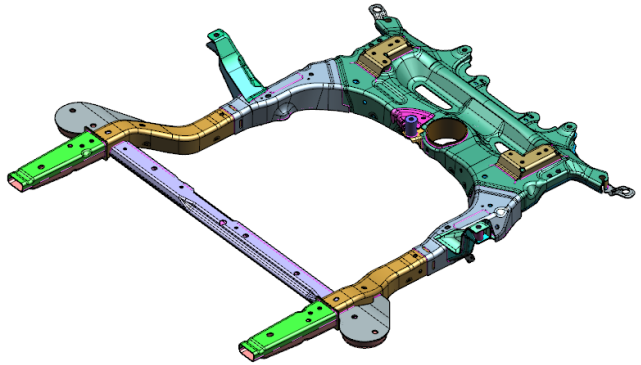
High Strength Steel-Aluminum Components by Vaporizing Foil Actuator Welding





Presenters: Glenn Daehn (PI)

The Ohio State University

June 3, 2020

Project ID: MAT132

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start Date: October 1st 2016
- End date: March 31st 2021
- Percent complete: 70%

Budget

- Total project funding
  - DOE share: $2,405,625
  - Contractor share: $301,902
- Funding FY 2019: $956,357
  - $854,031 DOE, $102,325 Contractor
- Funding FY 2020:
  - $387,269 DOE, $60,092 Contractor

Targets and Barriers*

- 25% weight reduction on a 2012 mid-size sedan
- Cost premium < $5/pound saved
- Equal or better strength and durability performance
- Predictive modeling and high-volume process for mixed-metal joining

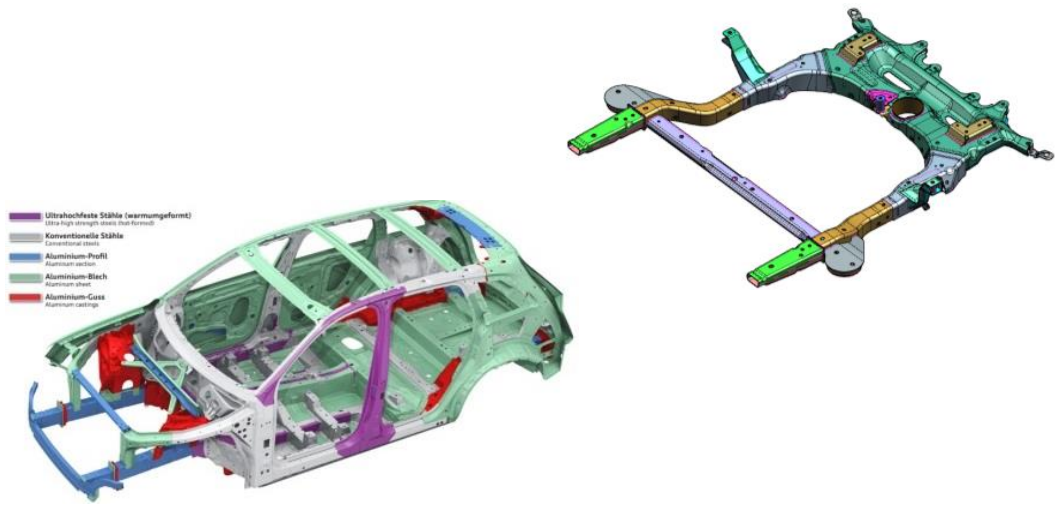
*Source: 2017 U.S. Drive MTT Roadmap Report, Section 4

Partners

- OSU (Lead)
- Magna
- Coldwater Machine Company
- Ashland
- PNNL
- Arconic
- Hydro (SAPA extrusions)

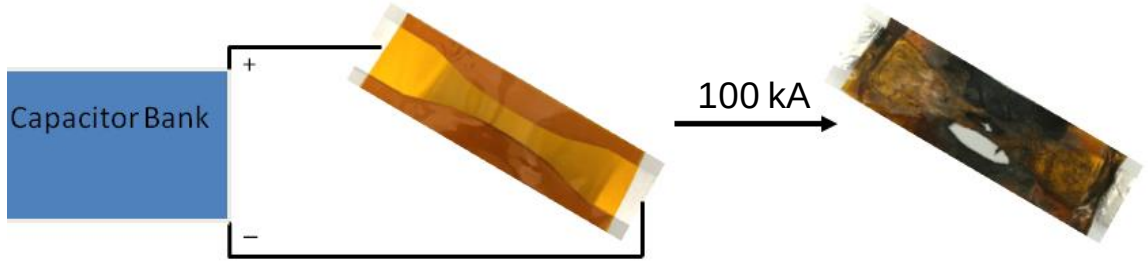
Relevance/Objectives

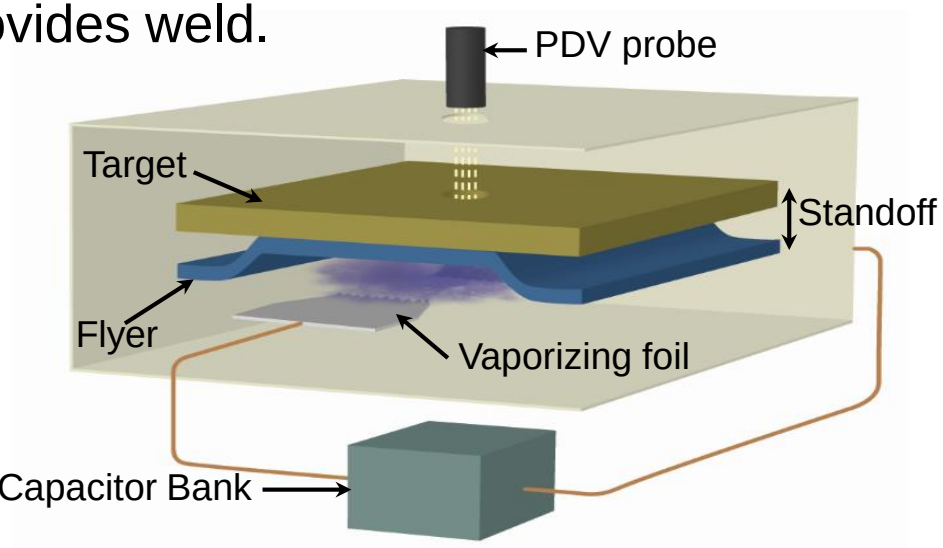
- Objective:
  - *Proposed* 20% weight reduction of a current all-steel automotive component from a 2016 mid-size sedan at a cost premium of $3/lb saved by developing a mixed-material joining technology capable of high-volume production
  - The produced component should meet or exceed strength and durability of incumbent component
  - Have a predictive modeling capability for relating process, structure and property of joints
- Project directly addresses the listed barriers and targets
- Impact:
  - This project accelerates and focuses the development of vaporizing foil actuator for production of an automotive component. At project completion, the technology will be ready for adoption within the research and development groups of Tier 1 and OEM for assembly of any mixed/advanced material bodies

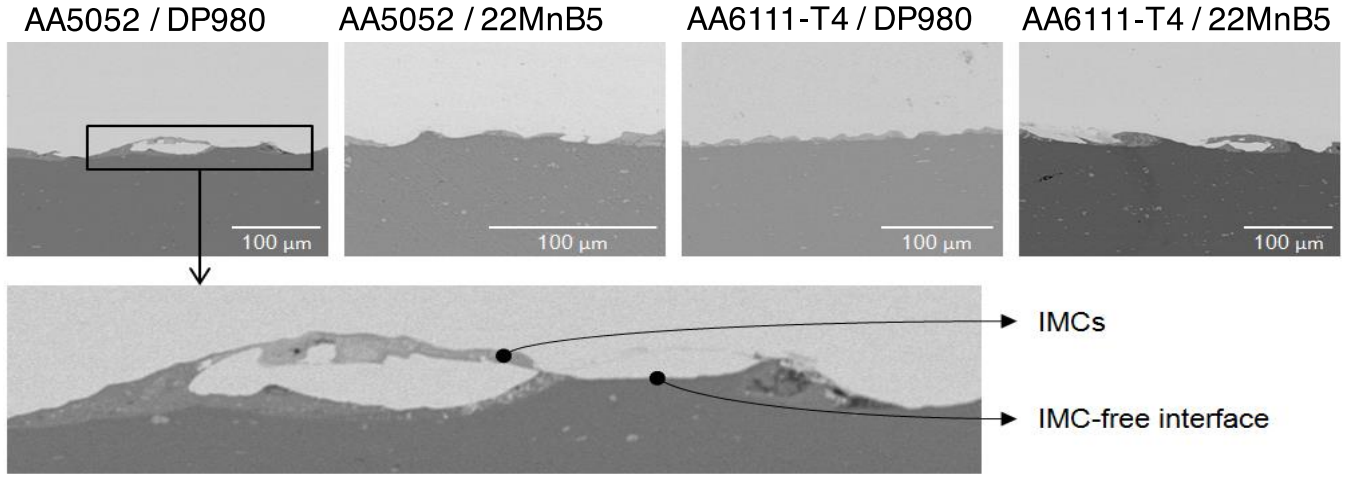


Approach – Impact Welding

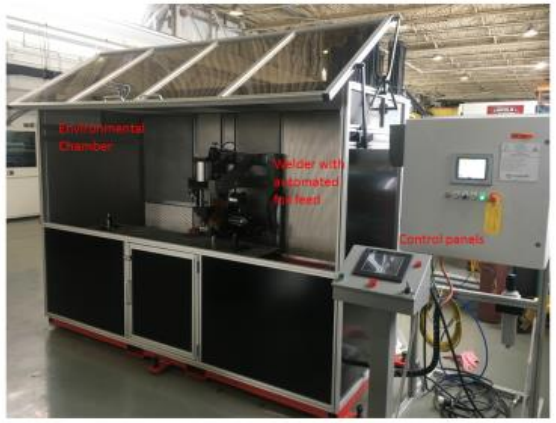
Solid-state impact welding of aluminum to steel
- nominal 500 m/s, 20° impact provides weld.

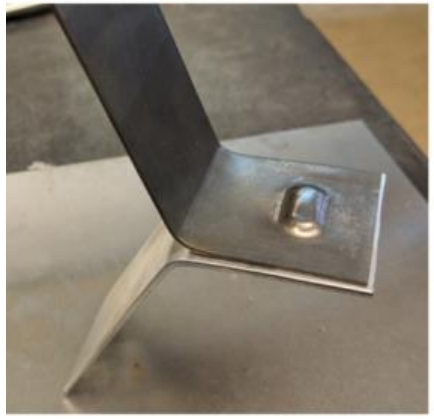


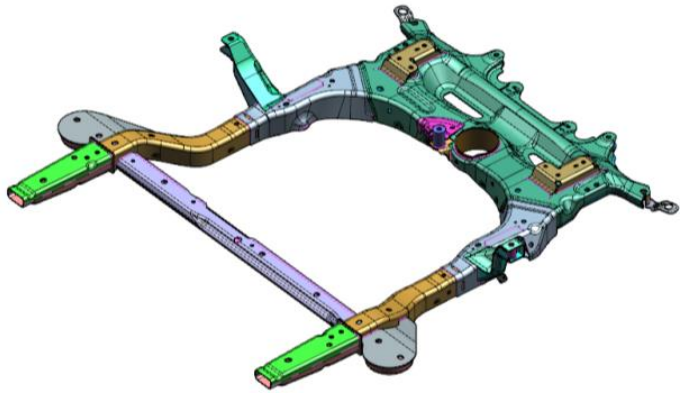




Approach

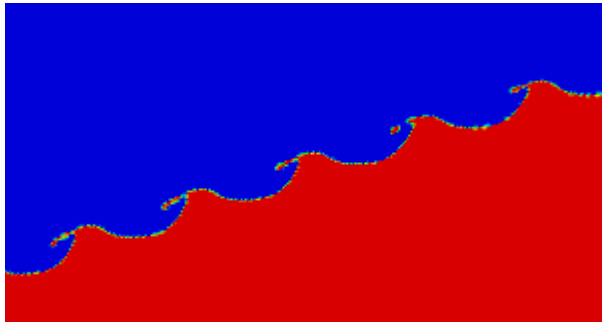




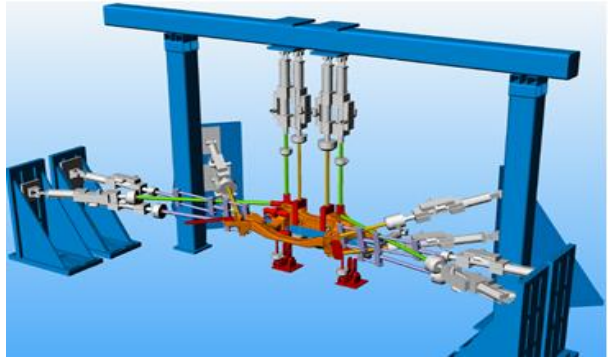


Process & tool development

Welding and testing Coupons



Microstructure Characterization and Modeling



Prototype build and durability testing

Technical Plan/Milestones

Major tasks	Oct 2016 – Sept 2017	Oct 2017 – Sept 2018	Oct 2018 – March 2019	April 2020 – March 2021
Coupon scale pre-screening	★			
Numerical model development and validation				
Coupon scale testing of down-selected material pairs				
Design for manufacturing of prototype component		★		
Production and testing of the prototype and its subcomponents			★	
Design and build of robotic welding system				★

★ **Go/No-Go Milestones**

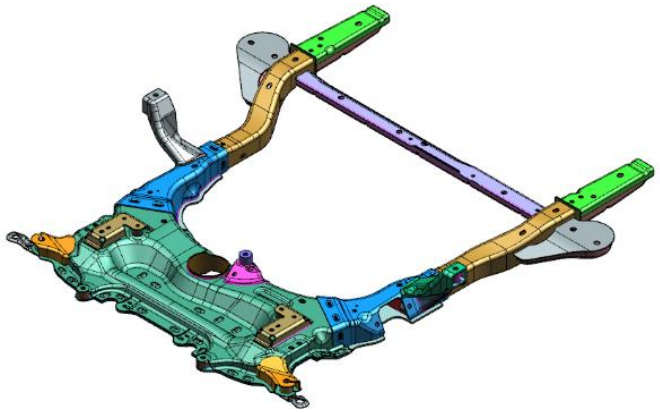
Budget Period 1: Three material clear down-selection criteria: (i) parent material failure during pry testing (ii)weld strength > 70% of weaker parent material (iii) post-corrosion strength > 80% of pre-corrosion strength

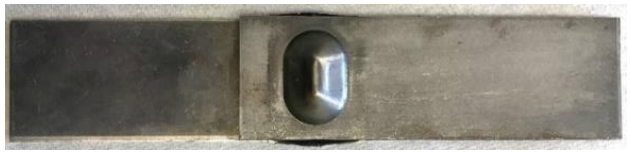
Budget Period 2: Release of prototype design that meets baseline requirement for strength, stiffness and durability

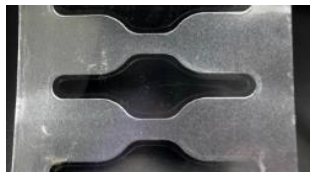
Budget Period 3: Strength and durability of prototype component design equal to or better than baseline component

FY18 Summary: Prototype design, coupon tests, and manufacturing system design

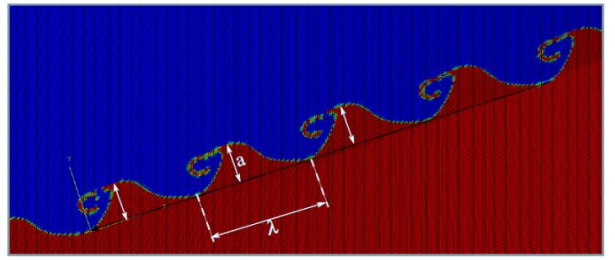
- Prototype design was complete and model-analyzed with 12% weight reduction achieved from baseline Chevrolet Cruze engine cradle weight of 24.4 kg
- VFA welding parameters were finalized
- Welds were lap-shear tested and max load > 16kN was obtained

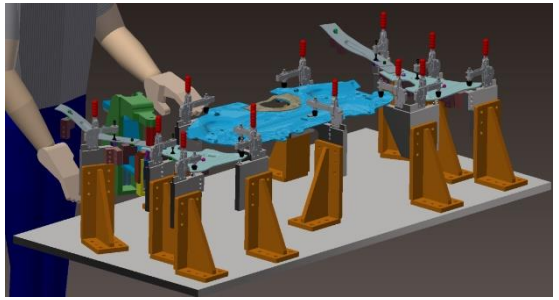






- Fatigue tests were performed at high, medium and low cycles
- Fast capacitor bank system was fabricated and tested
- VFAW fixtures and pre-prototype welding head were designed
- Process-structure computational model was validated





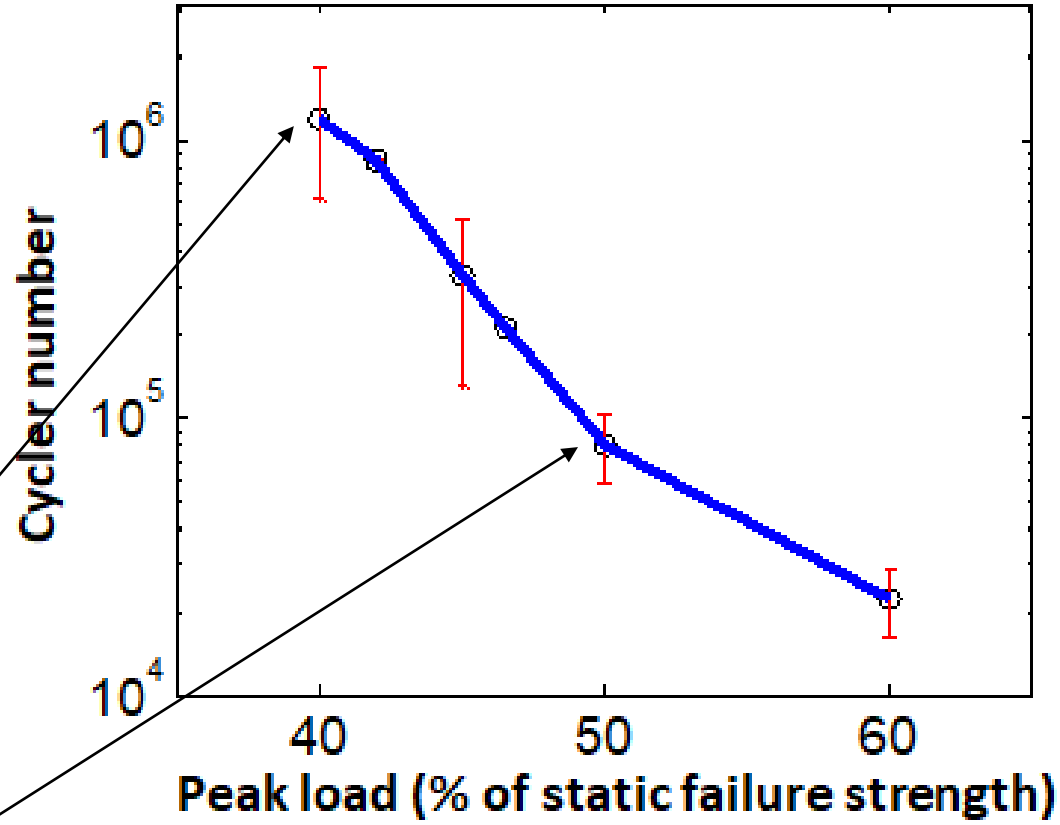
FY19 Technical Accomplishments

- Fatigue tests continued
- Weld head built
- Most sub-components formed, and all stamping dies designed and fabricated (about 50 constituent parts)
- Component fixturing built

Technical Accomplishment:

Fatigue tests at low, medium, and high cycles

- Fatigue tests were continued and completed
- 100% static load = 16.55 kN
- Cured adhesive around the weld
- High cycle fatigue limit > 30% of static strength
- Both interfacial and nugget failures were observed

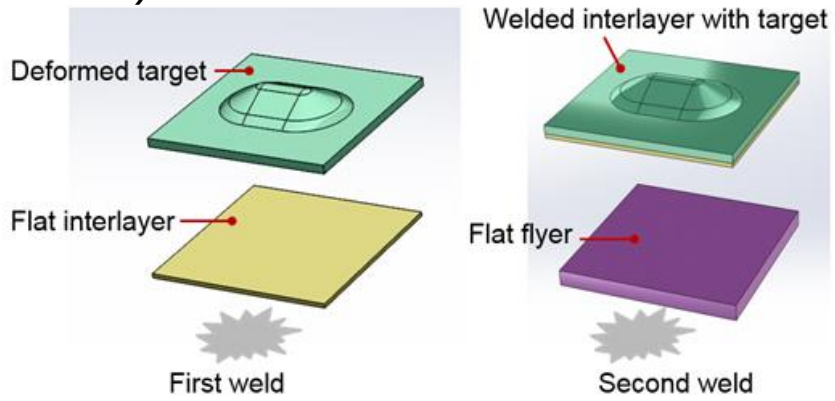


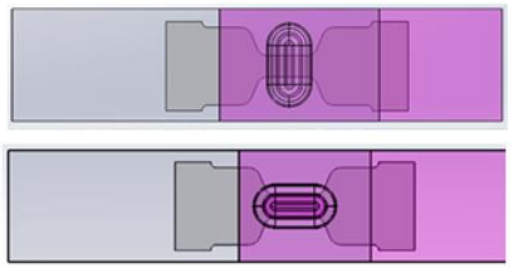
4mm AA5052-HSLA 340

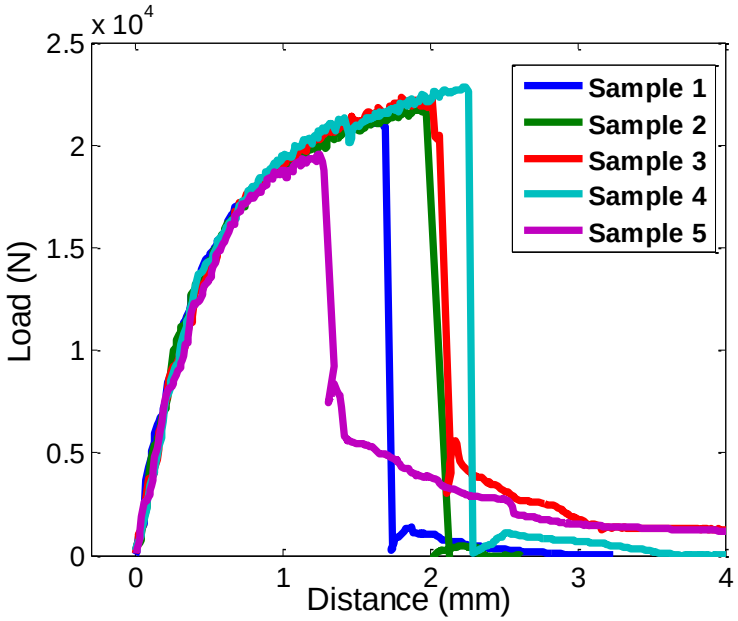
Technical Accomplishment:

Testing of final material pairs with modified VFAW method

- 4 mm AA5052, 4.2 mm and 4.5 mm AA5182 and 5.1 mm hot-rolled AA5052 as flyer were welded to HSLA 340
- Two-shot VFAW method was developed to ensure process robustness
- Max energy per shot is decreased to 3kJ from the previous year's 4kJ
- Qualified shear failure loads were obtained. (16 kN-24 kN, depending on the aluminum thickness)





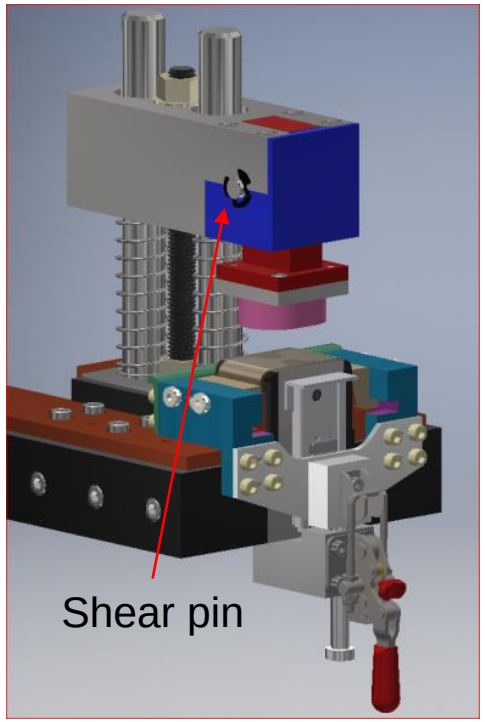


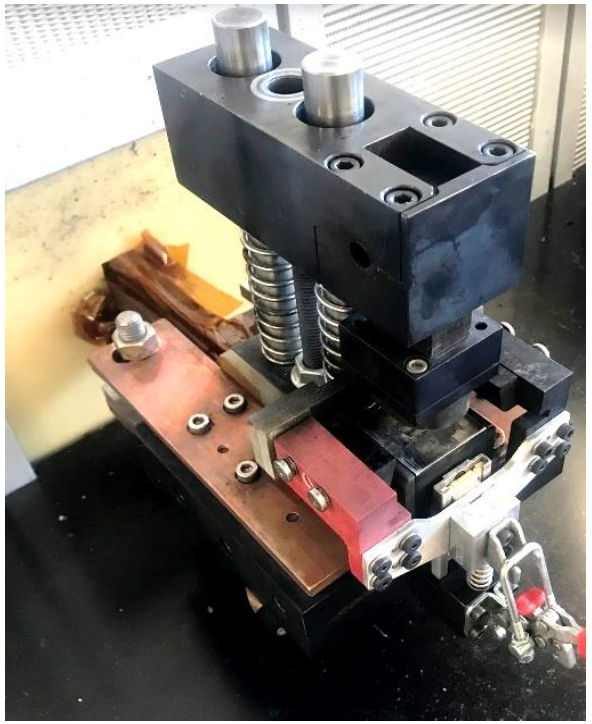
4mm AA5052-HSLA 340

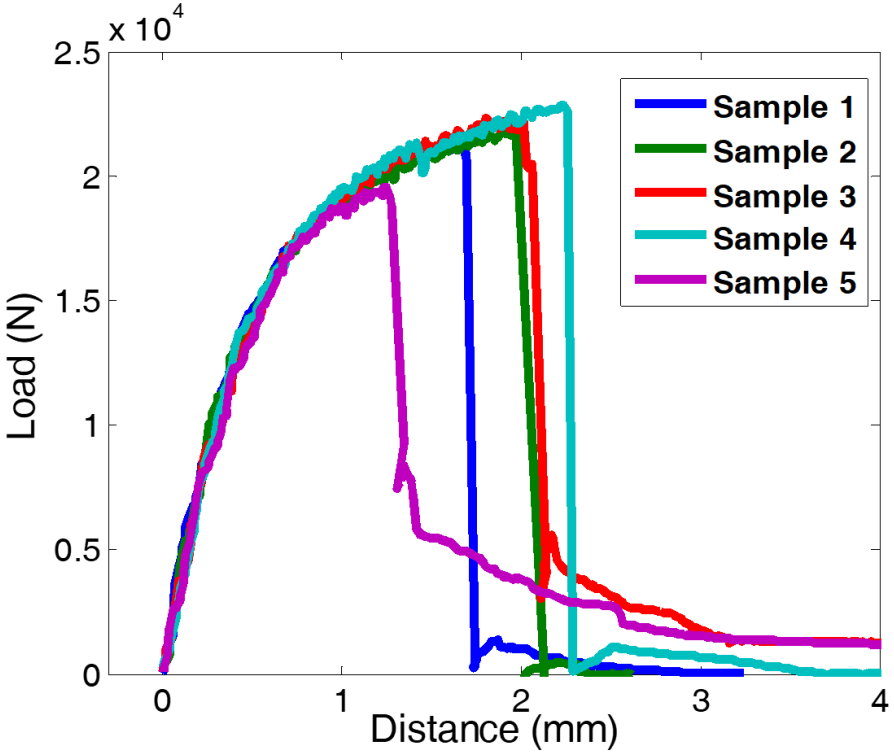
Technical Accomplishment:

Development of prototype weld head

- A pre-prototype weld head was designed, fabricated and tested.
- Quick change of anvil and breech and easy foil alignment was achieved.
- Using the shearing pin, the impact force of 3000 lbs was estimated at the input energy of 3.5 kJ.
- The weld head proved to operate properly at input energy less than 3.5 kJ.



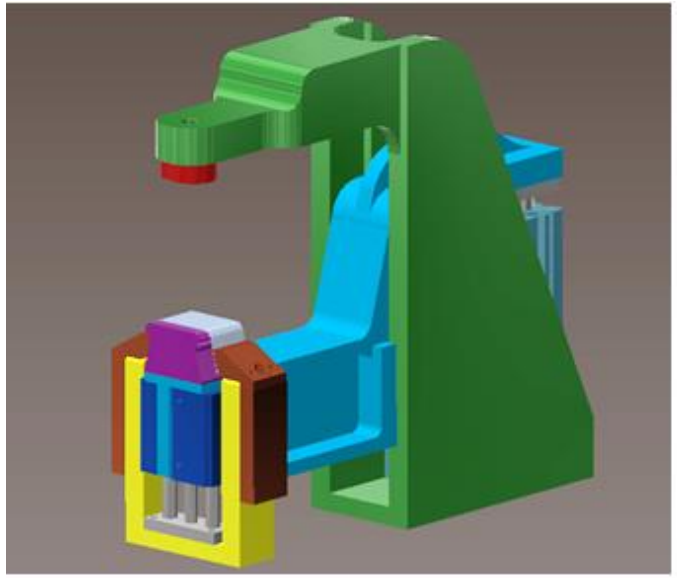




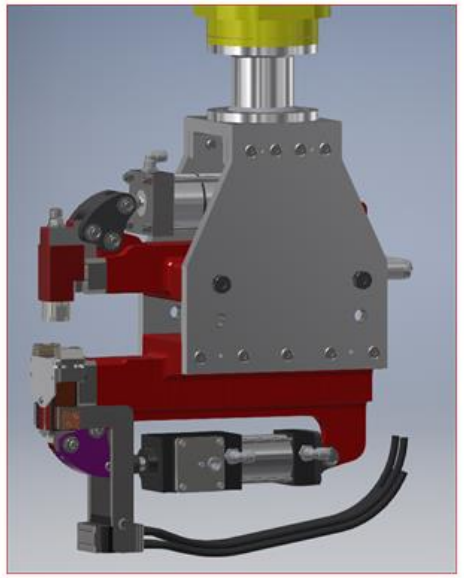
Technical Accomplishment:

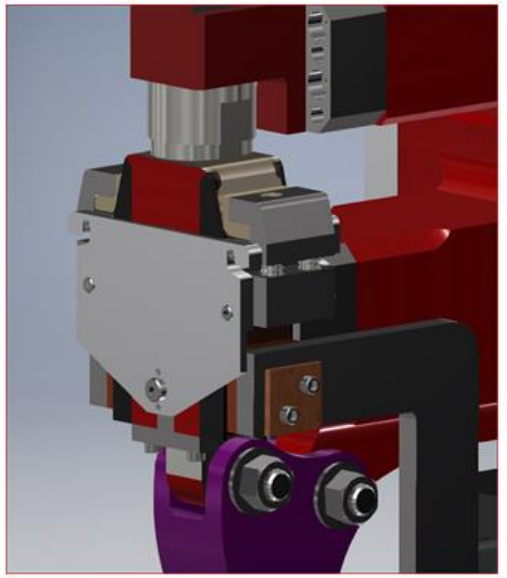
Design of prototype weld head

- The design prototype welding head was finalized.
- Quick change of anvil and breech, accurate foil placement and easy cleaning action will be achieved.
- Hydraulic cylinders will apply preload and backing force.
- Desired freedom of movement will be achieved by flexible co-axial cables.
- Will study noise mitigation from open weld head.



Starting design in FY18



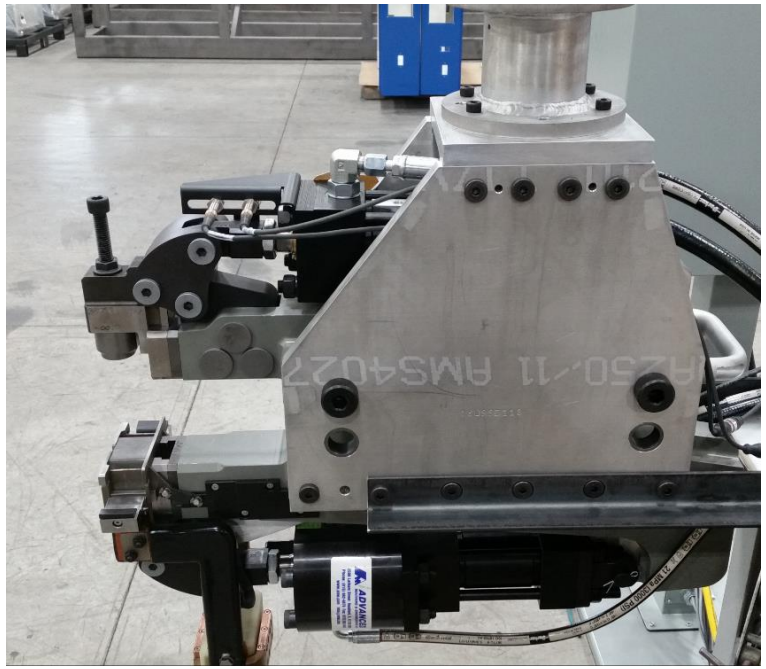


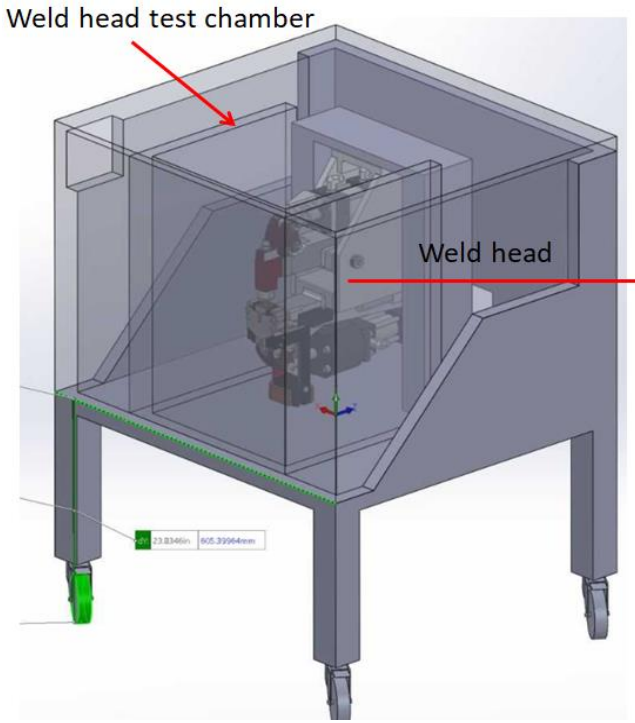
Design implemented for weld head production in FY19

Technical Accomplishment:

Development of prototype weld head

- Final, assembled weld head is awaiting testing.
- The foil clamping assembly is to be tested using two different materials
- A noise resist chamber is designed to cover the weld head during testing





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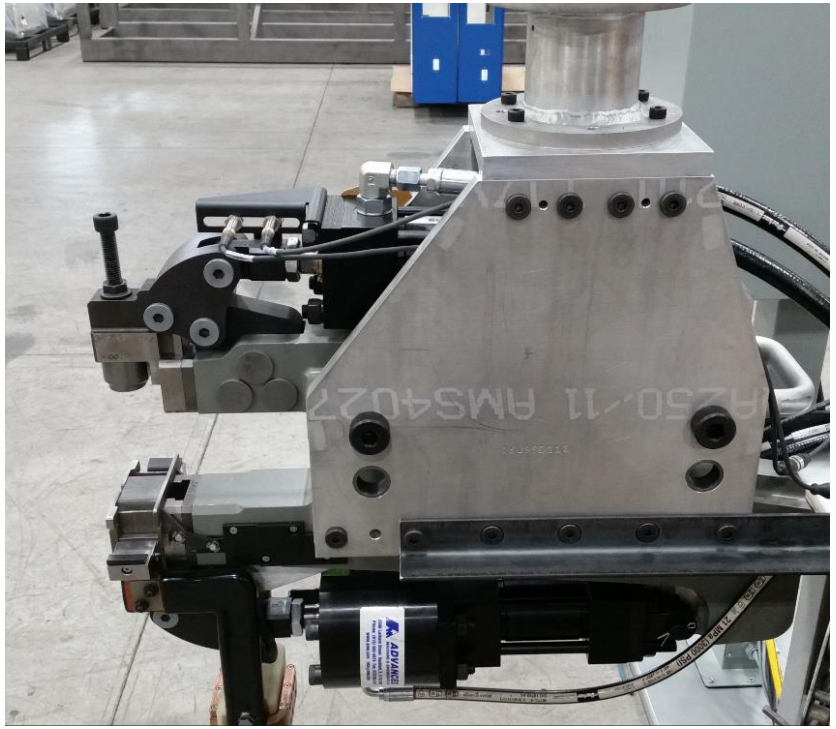
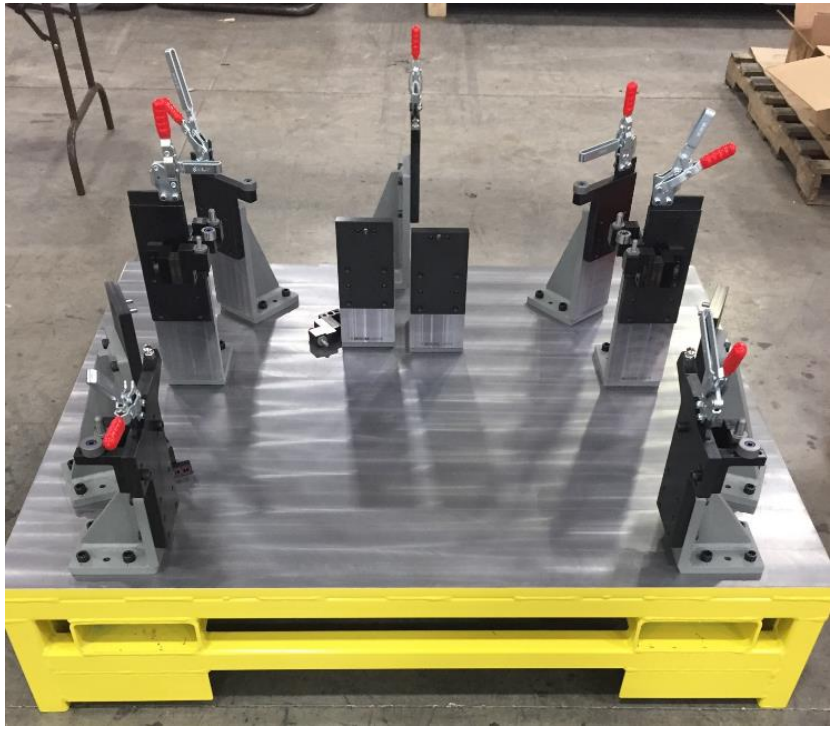


VFAW head



1 of 3 part holding fixtures during VFAW

Technical Accomplishment:

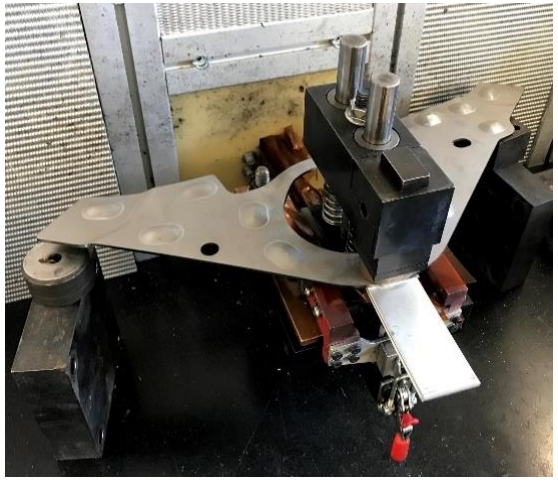
Fabrication of prototype components

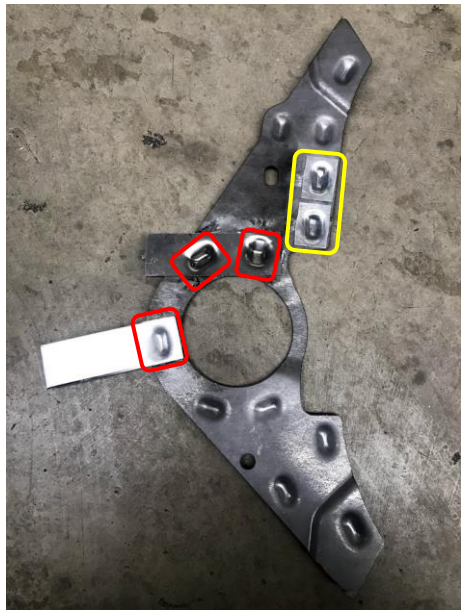
- 49 different steel and aluminum subcomponents stamped

Technical Accomplishment:

Welding test on prototype subcomponent in lab

- Using the pre-prototype weld head, 4.0 mm AA5754 and 5.1 mm hot-rolled AA5052 coupons were successfully welded to the 2.5 mm HSLA 340 subcomponent using the two-shot method.
- The energy input were reduced to 2.0 kJ and 3.0 kJ per shot, respectively.

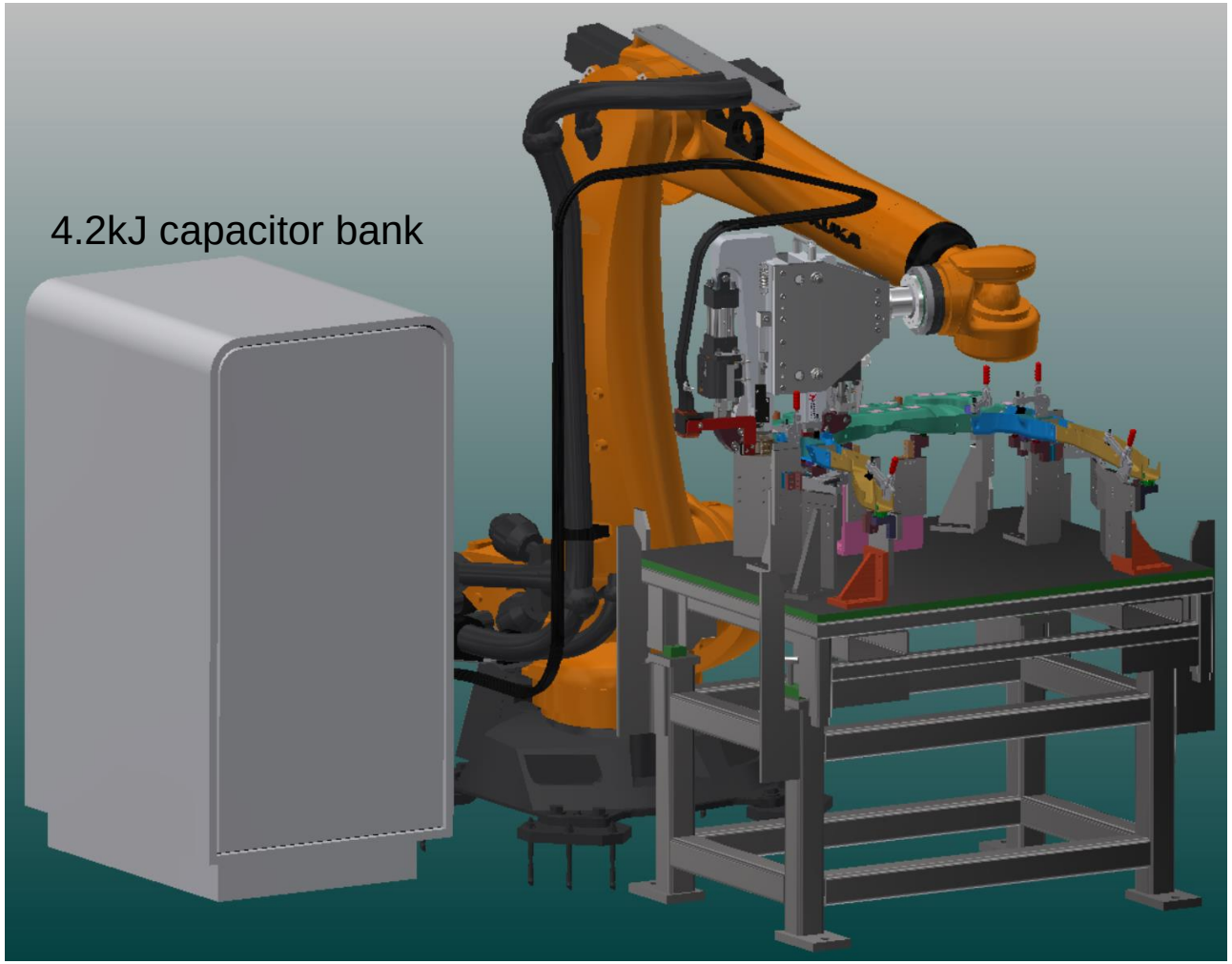




Technical Accomplishment:

All components for robotic welding ready

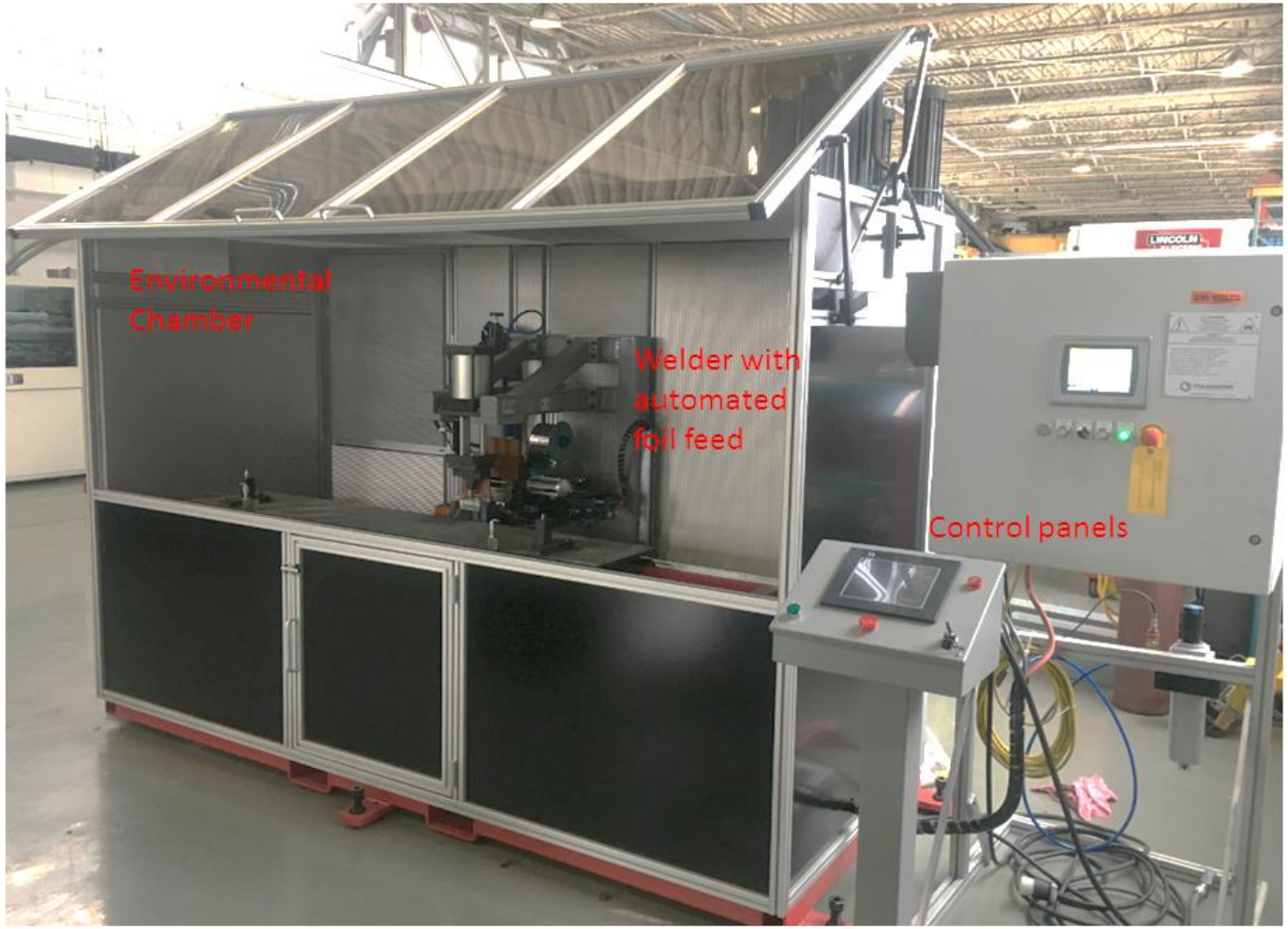
- 6-axis welding robot procured (KR 210 R3100 ultra F)
- Payload: 210 kg
- Max reach: 3095 mm



Technical Accomplishment:

Process Automation

- Designed for closed door, lights out automation of coupon scale testing
- Able to dispense coupons, apply adhesive, perform VFAW, clean the weld area, and dress electrodes
- Functionality tested and validated, but volume production not performed yet



FY18 Pedestal welder before adding much automation

Technical Accomplishment:

Process Automation

- Designed for closed door, lights out automation of coupon scale testing
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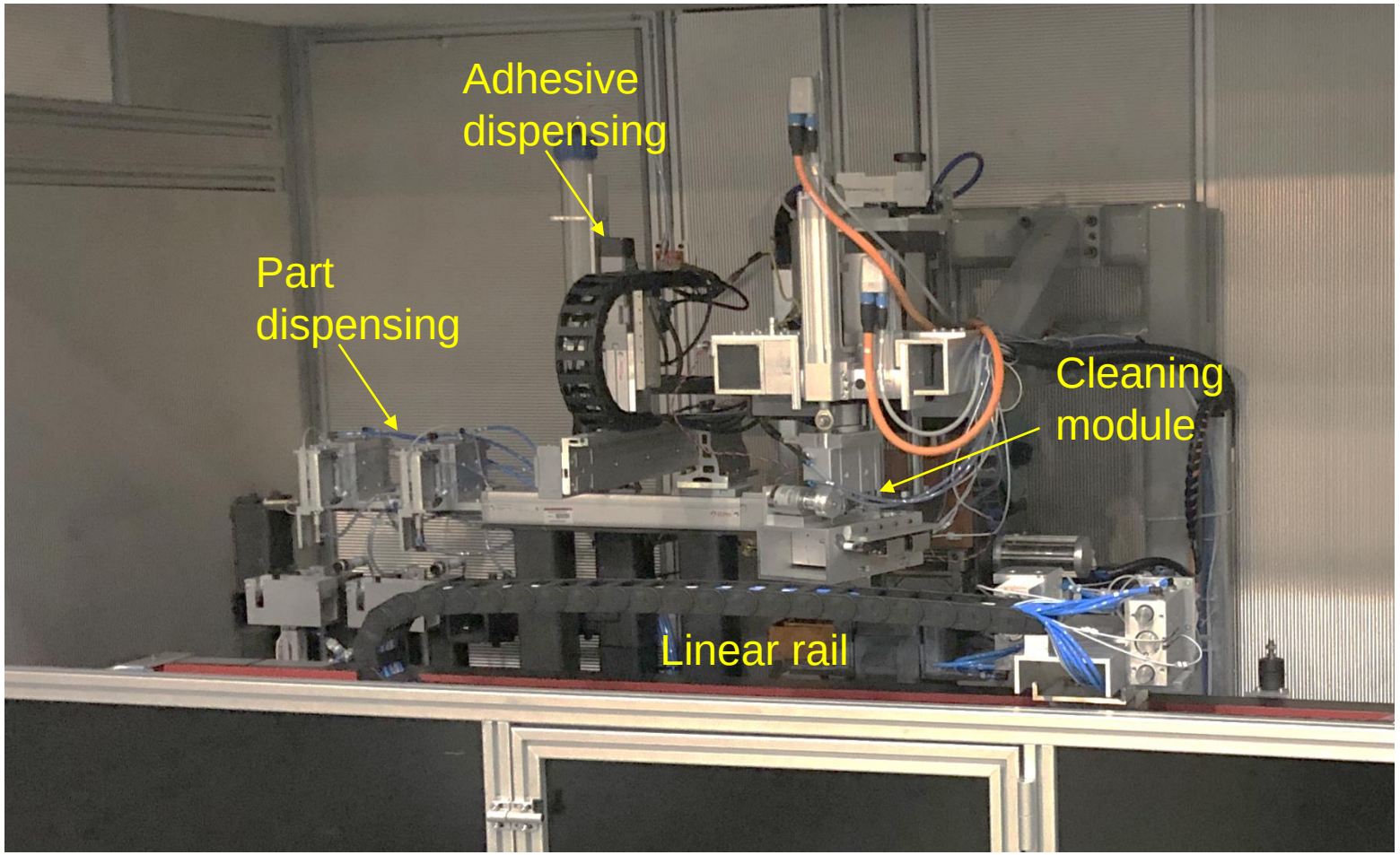


FY19 Pedestal welder with automated part handling, adhesive dispense and cleaning

Responses to Previous Year Reviewers' Comments

Comments were largely positive. Specific issues highlighted for further consideration:

1) Team should consider quantification of strains across weld interface and how this may affect durability.
Response: Yes, consideration of thermal and locked in strains will be considered with respect to fatigue and corrosion, using standard engineering models.

2) CAE correlation should be established to understand dimensional tolerance and most effective order of assembly.
Response: Yes, this will be considered, reported upon and effect on locked in strain will be assessed.

Collaboration and Coordination

- **OSU's Impulse Manufacturing Lab, Fontana Corrosion Center, CDME:** Facilities and expertise for impact welding, process development, standard corrosion testing at coupon and subcomponent level in addition to program management
- **Magna (Sub):** CAD, CAE, prototype build and testing
- **Coldwater Machine Company (Sub):** equipment builder and system integrator
- **PNNL:** Numerical simulation of impact welding process, interfacial wavy pattern and jetting, and mechanical performance of the welded coupons
- **Ashland:** Supplies structural adhesives for galvanic corrosion protection. Also provides in-house testing
- **Arconic:** Supplies 5xxx and 6xxx sheets for screening tests and prototype build
- **Hydro:** Supplies 6xxx and 7xxx grade aluminum extrusions for possible chassis and body side applications

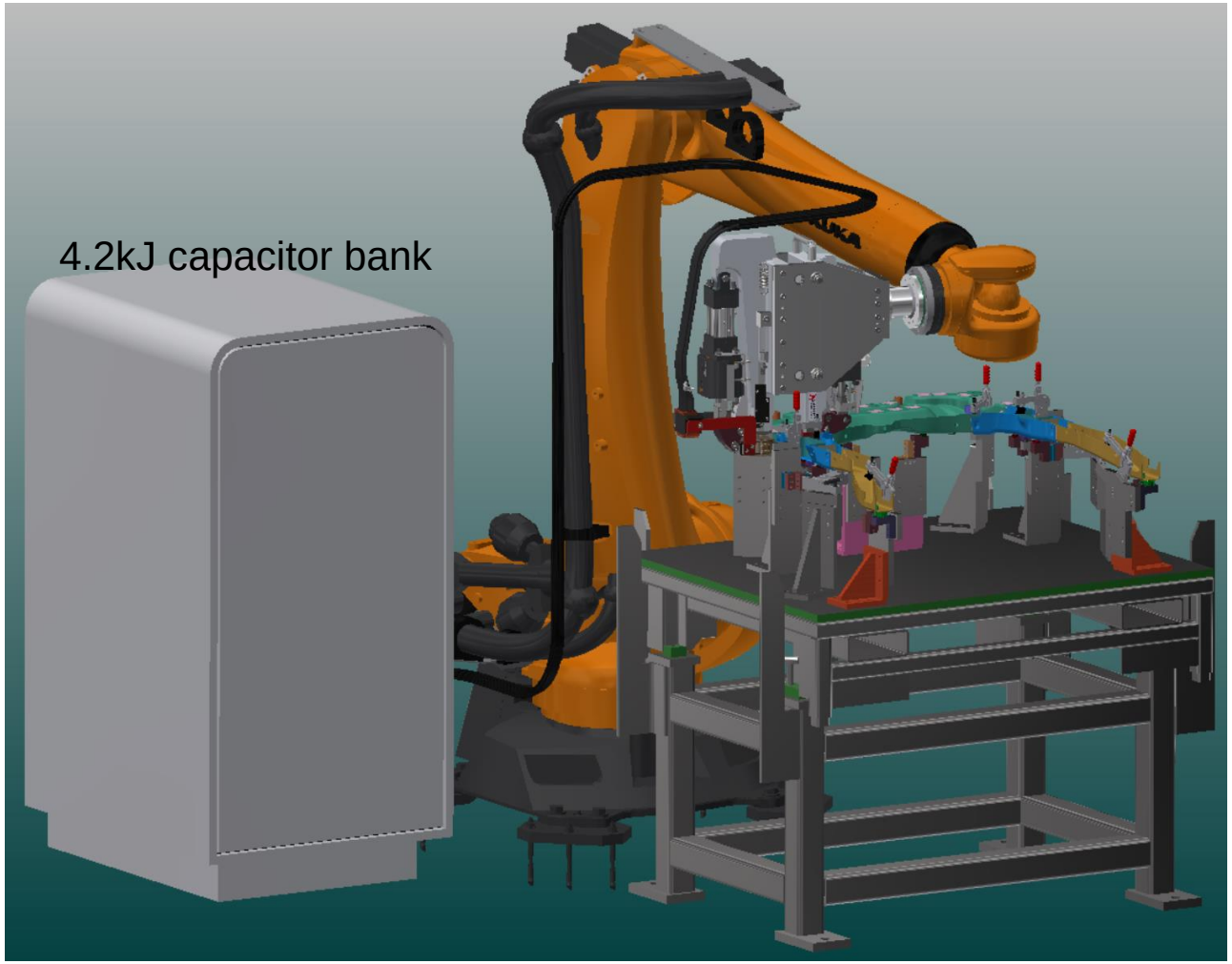
Remaining Challenges and Barriers

- Prototype scale assembly
- Weld cycle time
- Stack up tolerance to be determined
- Welding in presence of wet adhesive
- Tool and equipment life

Proposed Future Work

- Weld head testing at OSU
- Set up of work cell at Magna
- Prototype component assembly and durability testing at Magna
- Corrosion testing at OSU
- Testing of fully automated pedestal welding system at OSU
- Cost analysis of $/lb saved by OSU

*Any proposed future work is subject to change based on funding levels

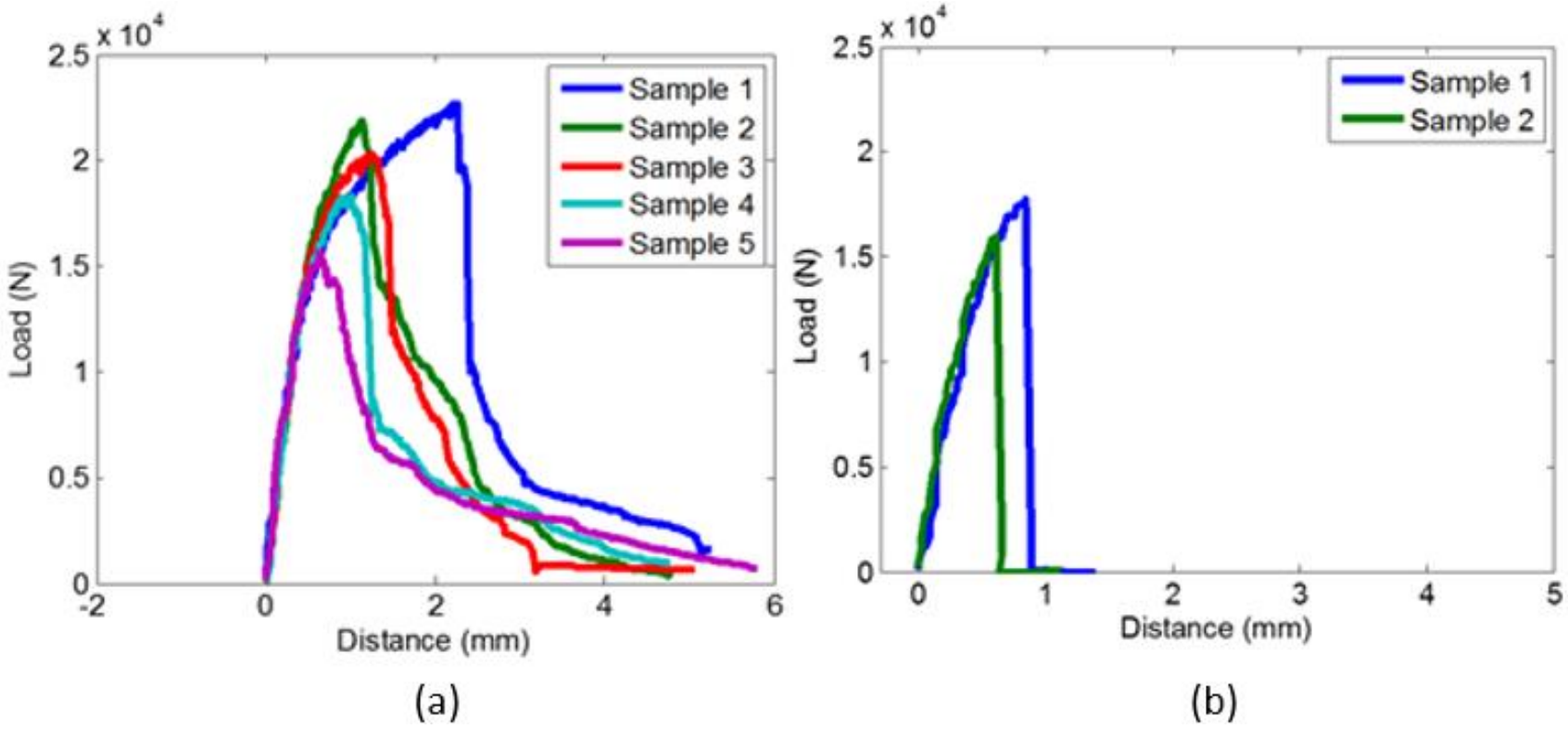


Summary

- Vaporizing Foil Actuator Welding (VFAW) is successfully welding stamping grade aluminum and steel pair in aluminum thickness relevant to sub-frame structures
- Welds are strong in static as well as cyclic loading and meet the requisite design criteria
- For robustness, a two-step process will be followed for prototype production
- A robotic weld head will be used for prototype assembly and is ready to use
- The subcomponents of the prototype have been stamped
- Testing of weld head at OSU, set up of weld cell at Magna and prototype assembly to commence once the lockdown is lifted

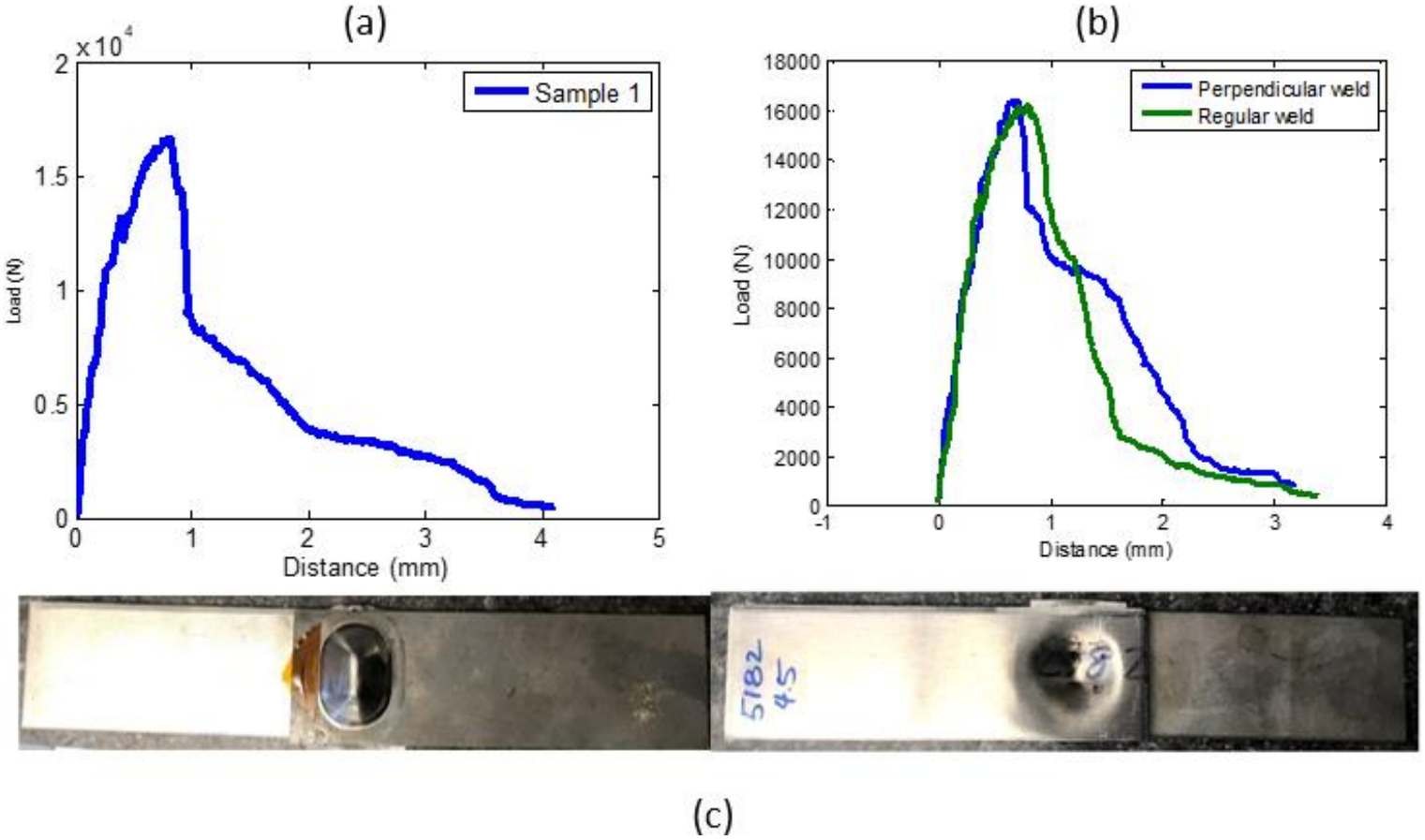
Technical Back-Up Slides

Lap shear tests



Lap shear tests of welds of 4 mm AA5052-HSLA 340 using: (a) the two-shot method; and (b) the single-shot method created with pre-prototype welding head

Lap shear tests



. Lap shear tests of (a) a weld of with 4.5 mm AA5182-HSLA 340 in the perpendicular direction; (b) welds of 5.1 mm hot-rolled AA5052-HSLA 340 in both directions; and (c) a photo of the front and back sides of a AA5182-HSLA 340 weld in the perpendicular direction.

Technical Accomplishment:

Upgrade of capacitor system

- Error found during system operation: random early accidental discharge, repeat firing, PLC time-out error.
- Solution: longer venting time, additional accidental-discharge detecting mechanism, program and sequence optimization
- Repeat firing and PLC time-out error have been solved.
- Random accidental discharge is dramatically decreased to minimal level.